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# Dimensional Changes in Certain Cotton, Wool, and Rayon Woven Fabrics During Various Cleaning and Pressing Processes

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## SUMMARY

Fabrics of different fibers and construction react very differently to various cleaning procedures. Some materials shrink; others stretch. In some the changes are negligible; in others they are excessive. To obtain more data on the dimensional changes that occur in certain woven fabrics, an investigation was made of the performance in laundering, dry cleaning, and wet cleaning of 30 cotton, rayon, and wool textile materials commonly used in clothing.

In addition, measurements were made of the creep, or elongation under tension, of all the fabrics when they were wetted out, in order

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to ascertain the feasibility of restoring shrunken fabrics to their original dimensions. Attempts were made to restore to their former size those that shrank, by wetting out and pressing them under tension.

Even though there was considerable variation in the dimensional changes resulting from laundering, dry cleaning, and wet cleaning within the fiber group, each type of fabric followed a somewhat definite pattern.

Shrinkage constituted most of the dimensional change, which for the most part, was in the warp direction. Laundering caused the most shrinkage and dry cleaning the least in the cottons and wools. The change in rayons was similar for laundering and wet cleaning.

Progressive shrinkage took place in the wools with each successive cleaning. With laundering it was particularly marked. The cottons exhibited a tendency toward progressive shrinkage in the first three treatments by all cleaning procedures. The rayons showed only a slight tendency toward progressive shrinkage in laundering but no such tendency in dry or wet cleaning.

For all cleaning methods the wools had the greatest amount of shrinkage and the continuous filament acetate the least. The continuous filament viscose rayons and the mixed spun acetate-viscose rayons had moderate shrinkage, in general less than that found in the spun viscose group. The shrinkage in the cottons was similar to that of the spun viscose fabrics. Stretching occurred chiefly in the rayon fabrics and then largely in the filling direction.

Shrinkage in all fabrics could be considerably reduced by applying tension to the wet or damp materials during the pressing. The rayons which shrank could easily be brought back to their original dimensions, but some of the cottons and wools could not be restored to their original size since they were not as easily stretched as the rayons.

In this study, the amount of shrinkage resulting when fabrics were wet-cleaned was not as large as when the fabrics were laundered. This is at variance with results of previous studies in which a different method of wet cleaning was used. Further investigation is needed to determine amounts of shrinkage during different cleaning processes.

## THE PROBLEM AND SCOPE OF WORK

Dimensional changes in fabrics during cleaning and pressing cover a wide range. Some materials shrink or stretch a negligible amount whereas others increase or decrease considerably in either length or width, or both. These changes vary not only because of the kind of treatment the fabrics receive in the many stages of their manufacture and during the cleaning process itself, but because of the inherent character of the textile fiber, the type of yarn, and the construction of the cloth.

Most fabrics when wet with water will shrink and if stretched during drying will shrink again on further wetting. This shrinkage is attributed to increase in crimp, yarn shrinkage, and fiber shrinkage (*5, 11, 21*).[2]

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[2] Italic numbers in parentheses refer to Literature Cited, p. 26.

Shrinkage in cotton fabrics is easy to predict and control; shrinkage in wool is often excessive and is difficult to govern; shrinkage and stretch in rayon fabrics vary widely and are hard to regulate.

Cotton in contrast to wool and rayon is a stable fiber. It swells when wet and returns to its original cross-sectional area with little change in length (*11*). Collins (*5*) has reported that most of the shrinkage in cotton cloth is due to increase in crimp.

Epelberg (*6*) and Powers (*16*) have described dimensional change in cotton fabrics as relaxation or mechanical shrinkage. When wet, the fabric is relaxed and recovers from the strains set up in the weaving and finishing operations. The shrinkage in cotton can be stabilized (controlled) mechanically, by wetting the fabric and allowing it to relax and draw up the amount it has been stretched.

Wool, on the other hand, differs considerably from the cotton fiber in its behavior towards water. It is possible to stretch wool much more than the cotton fiber and to shrink it again (*5*). Wool fibers, unlike cotton, felt easily if rubbed together when wet.

Wool fabrics may be shrunk mechanically by sponging—they may be dampened and allowed to recover slowly from the amount they have been stretched in their manufacture. This causes little felting. However, unlike cotton fabrics, wool cloth continues to shrink with each successive cleaning or wetting process. This progressive shrinkage is due to fiber felting.

Rayon when wet stretches quite easily and much more than cotton but not nearly as much as wool fiber. Rayon staple fibers mat under certain conditions but lack the felting properties of wool (*2*).

The performance of rayon fabrics in cleaning procedures is difficult to predict. A fabric may stretch with one wash and shrink with another. Some fabrics have been known to show progressive shrinkage (*1*). Considerable fiber shrinkage occurs in washing if the rayon has previously been stretched while wet or damp.

Because of the current demand for more data on shrinkage of woven fabrics, especially of wools and rayons, this study was made in order to ascertain the performance of some staple clothing fabrics during various cleaning processes. The investigation was concerned with the dimensional changes that occur in certain cotton, wool, and rayon fabrics commonly used for clothing, when cleaned by different processes. Four commonly used types of rayons were chosen in order to find out the general pattern of behavior of each type during cleaning processes in comparison to that of cotton and wool. This was done since the contradictory findings of other investigators concerning the performance of rayon fabrics when cleaned may have been due to differences in the types of rayons studied.

In addition to the measurements of dimensional changes of the cotton, wool, and rayon fabrics, determinations were made of the creep, or elongation under tension, of these fabrics when they were wetted out. Such information is fundamental to a study of shrinkage in textiles. From measurements of creep can be determined the feasibility of attempting to restore shrunken fabrics to their original dimensions. Unless fabrics elongate under tension they cannot be brought back to their original size.

## MATERIALS

Five fabrics each of cotton, wool, continuous filament acetate, continuous filament viscose, spun viscose, and spun acetate-viscose rayon were purchased on the retail market for this study. In order that various factors of construction would not influence their performance, all materials chosen were of plain weave, and in the fabrics composed of staple fibers the yarns had a moderate amount of twist. The physical properties of the test fabrics are reported in table 1. One of the cottons (fabric No. 2) had been mechanically shrunk. None of the wools or rayons had resinous treatments which inhibited shrinkage.

The group of cotton fabrics consisted of two percales, a chambray, a gingham, and a crash. The wools were of moderate weight and were suitable for dresses or summer suits. The continuous filament acetate and viscose rayon fabrics were those commonly used for women's slips and dresses. The spun viscose materials simulated cotton and linen fabrics and were types extensively used for women's dresses and blouses. The mixed spun acetate and viscose group were challis.

## EXPERIMENTAL PROCEDURE

Six 25-inch-square test specimens were cut from each of the 30 fabrics. Near the center a 10-inch square was marked, with a template as a guide to insure that all fabrics were marked exactly the same. Thread was sewed into the fabric, on the marks, at three points on each side. Pieces were cut from the corners of the large square in order that they might be placed in the tension device described by Kellner (*12*) and Wachter (*20*).

Specimens of all the fabrics were laundered, dry-cleaned, or wet-cleaned for five successive times. Of the six replicates of each of the 30 fabrics, 4 were laundered and 2 were dry-cleaned. One of the dry-cleaned sets was later wet-cleaned.

### Laundering

The fabrics were laundered in the textile laboratory of the Bureau of Human Nutrition and Home Economics in accordance with methods outlined in a standard test procedure. For the cottons the procedure for determining shrinkage in laundering of cotton and linen woven fabrics was used (*19, p. 30*); for the wools and rayons the procedure outlined for determining shrinkage in laundering of woven fabrics other than cotton and linen was followed (*19, p. 32*). Tap water of 12 parts per million hardness and a neutral high titer flake soap were used.

### Dry Cleaning

Through the cooperation of the National Institute of Cleaning and Dyeing, two specimens of each material were dry-cleaned under controlled conditions. The samples comprised part of a 40-pound load of acetate, viscose, and lightweight woolen clothes, and were conditioned at 30 percent relative humidity and 85° F. for at least 2 hours before cleaning.

TABLE 1.—*Physical properties of the cotton, wool, and rayon fabrics*

| Group and fabric No. | Weight per square yard [1] (conditioned) | Yarns per inch | | Yarn number [2] | | Twist [2] (directions and turns per inch) | | Fabric content | | Breaking strength [2] (raveled-strip method) | | | | Elongation [2] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Warp | Filling | Warp | Filling | Warp | Filling | Total sizing | Fiber content | Dry | | Wet | | Dry | | Wet | |
| | | | | | | | | | | Warp | Filling | Warp | Filling | Warp | Filling | Warp | Filling |
| | *Ounces* | *Number* | *Number* | *Cotton system* | *Cotton system* | *Number* | *Number* | *Percent* | *Percent* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Percent* | *Percent* | *Percent* | *Percent* |
| Cotton: | | | | | | | | | | | | | | | | | |
| 1 | 2.3 | 61 | 56 | 33.63 | 38.59 | Z22.6 | Z21.7 | 5.0 | 95.0 | 40.2 | 21.2 | 38.2 | 21.8 | 5.3 | 12.7 | 10.0 | 14.3 |
| 2 | 2.9 | 85 | 78 | 42.55 | 43.00 | Z26.9 | Z24.6 | 3.8 | 96.2 | 34.7 | 34.2 | 43.8 | 38.4 | 7.0 | 10.3 | 9.3 | 12.3 |
| 3 | 2.8 | 71 | 56 | 31.38 | 36.32 | Z23.5 | Z29.0 | 5.3 | 94.7 | 37.0 | 20.6 | 42.2 | 24.2 | 7.3 | 15.3 | 9.3 | 13.0 |
| 4 | 3.3 | 64 | 48 | 32.88 | 21.38 | Z21.3 | Z21.4 | 3.3 | 96.7 | 27.7 | 30.4 | 28.4 | 29.6 | 11.0 | 13.3 | 13.3 | 12.7 |
| 5 | 3.4 | 72 | 71 | 31.76 | 32.12 | Z23.4 | Z23.6 | 2.9 | 97.1 | 39.1 | 42.4 | 47.6 | 48.6 | 9.7 | 13.0 | 14.3 | 18.3 |
| Wool: | | | | | | | | | | | | | | | | | |
| 1 | 5.9 | 45 | 40 | 32.89 | 34.82 | Z18.0 S17.4 | Z19.6 S19.7 | .1 | 99.9 | 18.8 | 14.6 | 10.1 | 8.2 | 18.3 | 22.7 | 49.7 | 50.7 |
| 2 | 4.6 | 39 | 23 | 54.84 | 13.55 | S8.9 | S9.6 | 0 | 100.0 | 18.0 | 13.6 | 12.1 | 8.6 | 29.3 | 16.7 | 50.7 | 42.3 |
| 3 | 6.2 | 32 | 24 | 18.82 | 18.67 | S14.4 | S16.1 | .6 | 99.4 | 19.2 | 13.0 | 11.8 | 11.7 | 23.3 | 27.0 | 47.7 | 50.7 |
| 4 | 4.5 | 59 | 47 | 50.00 | 50.59 | S17.9 Z15.8 | S16.8 | 0 | 100.0 | 27.4 | 22.2 | 17.1 | 12.8 | 30.0 | 26.0 | 56.7 | 53.7 |
| 5 | 6.0 | 28 | 28 | 21.30 | 17.36 | S12.6 | S12.9 | 0 | 100.0 | 16.6 | 17.7 | 11.8 | 11.7 | 18.0 | 25.3 | 47.7 | 50.7 |
| Acetate rayon (continuous filament): | | | | | | | | | | | | | | | | | |
| 1 | 2.6 | 99 | 65 | 96.95 | 152.04 | Z2.5 | Z3.9 | 2.0 | 98.0 | 20.8 | 20.7 | 11.0 | 12.2 | 8.7 | 13.0 | 15.3 | 25.7 |
| 2 | 2.4 | 98 | 63 | 94.18 | 148.17 | S1.8 | Z3.8 | 1.1 | 98.9 | 27.4 | 25.4 | 14.9 | 14.0 | 20.3 | 26.3 | 25.0 | 32.0 |
| 3 | 2.6 | 133 | 72 | 90.85 | 93.90 | S3.8 | S3.5 | 1.0 | 99.0 | 35.8 | 18.6 | 17.8 | 9.4 | 24.3 | 25.7 | 29.3 | 34.7 |
| 4 | 2.6 | 99 | 63 | 93.10 | 152.70 | S3.0 | Z4.9 | 1.5 | 98.5 | 28.6 | 26.4 | 14.6 | 14.7 | 17.3 | 26.0 | 23.3 | 37.0 |
| 5 | 2.7 | 90 | 61 | 139.35 | 147.25 | S2.9 | S2.6 | 1.2 | 98.8 | 34.2 | 21.8 | 17.4 | 11.4 | 23.7 | 29.7 | 32.3 | 39.0 |
| Viscose rayon (continuous filament): | | | | | | | | | | | | | | | | | |
| 1 | 4.0 | 49 | 49 | 306.70 | 313.00 | S3.2 | S2.4 | 1.0 | 99.0 | 75.8 | 62.0 | 37.6 | 34.2 | 20.0 | 16.7 | 21.3 | 17.0 |
| 2 | 3.1 | 73 | 75 | 153.65 | 158.00 | Z2.5 | S22.5 | 1.3 | 98.7 | 39.6 | 27.4 | 11.4 | 11.0 | 21.0 | 14.7 | 16.0 | 16.3 |
| 3 | 3.0 | 99 | 73 | 101.80 | 157.30 | S3.8 | S3.4 | 1.5 | 98.5 | 29.4 | 29.2 | 7.5 | 8.6 | 14.7 | 14.3 | 9.0 | 8.0 |
| 4 | 2.6 | 95 | 67 | 100.90 | 150.35 | S5.9 | S3.0 | 2.3 | 97.7 | 35.8 | 37.8 | 12.4 | 13.8 | 23.0 | 24.3 | 23.7 | 21.3 |
| 5 | 2.8 | 95 | 69 | 99.75 | 158.20 | S3.6 | S3.1 | 1.8 | 98.2 | 35.4 | 40.1 | 17.6 | 17.8 | 14.3 | 18.3 | 15.7 | 16.3 |
| Spun viscose (cotton texture): | | | | | | | | | | | | | | | | | |
| 1 | 3.7 | 68 | 42 | 32.46 | 13.61 | Z20.0 | Z14.0 | 1.4 | 98.6 | 41.0 | 45.4 | 18.6 | 25.0 | 24.3 | 18.3 | 20.7 | 20.7 |
| 2 | 3.7 | 82 | 58 | 30.59 | 37.27 | Z20.0 | Z23.6 | 6.1 | 93.9 | 48.8 | 25.1 | 27.2 | 13.6 | 24.0 | 20.3 | 24.7 | 17.7 |
| 3 | 2.8 | 134 | 89 | 59.80 | 59.15 | Z30.0 | Z29.0 | 8.0 | 92.0 | 40.8 | 32.2 | 26.4 | 21.4 | 13.0 | 15.0 | 14.3 | 14.3 |
| 4 | 4.2 | 72 | 41 | 26.61 | 13.24 | Z18.2 | Z11.8 | 12.0 | 88.0 | 51.9 | 57.4 | 32.1 | 34.2 | 12.3 | 15.3 | 16.3 | 15.7 |
| 5 | 5.8 | 46 | 44 | 12.46 | 12.06 | Z13.7 | Z18.3 | 15.1 | 84.9 | 53.2 | 47.6 | 33.4 | 24.6 | 11.7 | 22.7 | 15.0 | 19.0 |

See footnotes at end of table.

TABLE 1.—*Physical properties of the cotton, wool, and rayon fabrics*—Continued

| Group and fabric No. | Weight per square yard [1] (conditioned) | Yarns per inch | | Yarn number [2] | | Twist [2] (directions and turns per inch) | | Fabric content | | Breaking strength [2] (raveled-strip method) | | | | Elongation [2] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Dry | | Wet | | Dry | | Wet | |
| | | Warp | Filling | Warp | Filling | Warp | Filling | Total sizing | Fiber content | Warp | Filling | Warp | Filling | Warp | Filling | Warp | Filling |
| Spun acetate and viscose (wool texture): | *Ounces* | *Number* | *Number* | *Cotton system* | *Cotton system* | *Number* | *Number* | *Percent* | *Percent* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Percent* | *Percent* | *Percent* | *Percent* |
| 1 | 3.4 | 76 | 63 | 29.52 | 31.79 | Z19.2 | Z20.6 | 3.0 | [3] 30.8<br>[4] 66.2 | 35.3 | 28.1 | 18.2 | 12.6 | 16.3 | 24.0 | 17.0 | 18.3 |
| 2 | 3.0 | 74 | 58 | 30.25 | 33.07 | Z20.7 | Z21.0 | 2.0 | [3] 29.9<br>[4] 68.1 | 38.2 | 28.0 | 19.1 | 13.3 | 17.7 | 19.3 | 16.3 | 17.0 |
| 3 | 3.4 | 84 | 60 | 28.44 | 36.00 | Z19.9 | Z24.6 | 1.8 | [3] 33.9<br>[4] 64.3 | 44.8 | 22.0 | 20.8 | 9.8 | 23.3 | 21.3 | 22.0 | 15.7 |
| 4 | 4.4 | 73 | 54 | 21.83 | 20.74 | Z17.6 | Z16.2 | 1.1 | [3] 50.7<br>[4] 48.2 | 45.5 | 33.6 | 26.8 | 19.0 | 19.0 | 20.7 | 22.7 | 21.3 |
| 5 | 4.7 | 68 | 55 | 20.44 | 17.85 | Z19.3 | Z18.0 | 3.4 | [3] 52.8<br>[4] 43.8 | 42.9 | 36.8 | 24.6 | 21.6 | 18.7 | 20.7 | 22.7 | 22.3 |

[1] Mean of 5 determinations. [2] Mean of 10 determinations. [3] Acetate. [4] Viscose.

The load was then cleaned in a 30- by 48-inch dry-cleaning washer with a 10-inch solvent level. To the Stoddard solvent was added 80 liquid ounces of stock soap solution, composed of 20 ounces of Stoddard solvent, 40 ounces of water, and 20 ounces of a typical commercial dry-cleaning soap.

At the end of a 25-minute soap run, the load was given a 20-minute filter rinse, the flow rate of which was 2,000 gallons per hour. The load was then extracted in a 30-inch centrifugal extractor and placed in a tumbler where it was rotated for 20 minutes in hot air which did not exceed 160° F., then for 5 minutes in cold air. This dry-cleaning procedure was somewhat more severe than that encountered with average dry-cleaning methods because of the high water content in the solvent which was about 5 to 6 percent of the weight of the load.

## Wet Cleaning

One set of the dry-cleaned specimens was wet-cleaned in the Bureau's laboratory by a procedure which followed closely the method used in commercial establishments.

Softened water of 90° to 100° F. was used in all steps of this procedure and for all groups of fabrics except the wools. For the wool fabrics the wetting-out water and the soap solution were kept at 90° and the rinses at 80°.

The liquid wet-cleaning soap, the same as that widely used in commercial cleaning plants, was a neutral low titer soap with a coconut oil base. The stock solution consisted of 33 grams of soap and 4 grams of borax to 1 liter of softened water.

Each fabric specimen was cleaned separately. Two-liter beakers containing approximately 1,500 cc. of water were used for wetting out and rinsing. After wetting out for 3 minutes the sample was placed on a flat sloping stone drainboard, brushed with the soap solution in the warp direction with brushes similar to those used in commercial wet cleaning, and allowed to stand for 3 minutes. All samples except the wools were then given three 1-minute rinses, each in a separate beaker of water. Because the wools absorbed more soap than the other fabrics, they had to be rinsed more times.

After the wetting out and between rinses the specimen was lifted, with cupped hands as a basket, and allowed to drip, thus eliminating squeezing or wringing. The five fabrics in each group were extracted together in the spinning compartment of an electric home washer for approximately ½ to 1 minute, just long enough to remove excess moisture. The cotton samples were spread out on screens to dry in the air at room temperature; the rayons and wools were rolled in towels and allowed to remain until pressed.

## Pressing

After each cleaning procedure all specimens were pressed under various tensions in a machine (*12, 20*) in which two adjacent sides of the fabric were fastened into stationary clamps and the other two sides into movable clamps to which weights could be applied.

Before pressing, the dry specimens of laundered cotton materials were sprinkled uniformly, rolled, and allowed to stand for 5 minutes. The dry- and wet-cleaned samples were clamped into the pressing ma-

chine while dry and covered with a muslin cloth which had been wrung out as dry as possible from distilled water. A perforated aluminum plate was placed over the 10-inch square marked on the specimen and heated by an electric flat iron to 275° to 300° F. Both the iron and plate were lifted several times to allow steam to escape. The press cloth over the dry-cleaned samples was removed while it was still a little damp and the hot plate put directly on the sample until the fabric was thoroughly dry.

After the second, third, fourth, and fifth cleanings the specimen was clamped into the machine and the weight applied first in the direction which shrank the most. After the sample was pressed, the weights were removed at the same time so as not to pull the material out of shape. When the sample was removed from the presser the tabs were ironed dry and the fabric laid on a flat table. After 1 hour measurements were made at three places in both the warp and filling directions.

Both the dry-cleaned and wet-cleaned samples of each fabric were pressed under ½-pound tension. Of the four laundered specimens three were pressed under ½, 2, and 4 pounds tension, respectively. The fourth specimen was pressed successively with all three tensions.

After the fourth specimen was pressed under ½-pound tension and measured it was placed in a beaker of distilled water at room temperature for 5 minutes. The excess water was squeezed out; the sample was rolled in a towel and allowed to stand approximately 15 minutes before pressing with the 2-pound tension. The same process was repeated for the 4-pound tension.

## Measurement of Creep

Creep measurements under constant load were made at room temperature on wetted-out strips in both the lengthwise and crosswise directions of each fabric. On a strip 4 inches wide and approximately 25 inches long a 10-inch length was accurately marked at three places. The strip was wetted out in distilled water for ½ hour, then clamped into the tension device under a tension of 4 pounds. It was kept saturated by extending along its entire length a cotton wick, one end of which was immersed in a beaker of water. Measurements were made at the end of 1, 100, and 1,000 minutes. From the mean of three measurements the percent of elongation (strain) was calculated for each time interval.

## Restoring Specimens to Original Size

Guided by results of the measurement of creep, attempts were made, after five successive cleanings, to restore the six specimens of each fabric to their original dimensions. The samples were wetted out in distilled water at room temperature for 15 minutes, then rolled in a towel for 5 minutes before being clamped into the machine for pressing. Just enough weight was applied in the warpwise and fillingwise directions to bring the marked area to 10 inches on each side. The fabrics were then pressed until dry and, after standing for 1 hour without tension, were measured.

Specimens that could not be restored to their original length and width with less than 12 pounds of tension were pressed under tension

of a 12-pound weight applied in both directions. This weight exerted a tension of approximately 1 pound per 1 inch of width of fabric since the weight was supported by an approximate 12-inch width. Thus the tension was equivalent to that used in the measurement of creep.

## RESULTS

The data revealed differences in the dimensional changes of the six groups of fabrics as a result of laundering and dry and wet cleaning. Figures 1, 2, and 3 show the effect of five successive launderings and pressings under tension of ½ pound. Similarly, results of successive dry and wet cleaning followed by pressing under tension of ½ pound are shown in figures 4 through 8. Irrespective of the treatment, shrinkage constituted by far the greater part of the dimensional changes. On the whole the cottons shrank more in the filling than in the warp, whereas with the wool the greater dimensional change was in the warp direction. In most of the continuous filament acetate rayons, the amount of shrinkage was about the same in both directions. About two-thirds of the other three groups shrank more in the warp than in the filling. The stretching that occurred in a few of the materials was usually in the crosswise direction.

### Effect of Laundering

Laundering caused considerably greater shrinkage in the wool fabrics than in any of the others. After 5 washings warp shrinkage ranged from 13.5 to 27.5 percent; filling shrinkage, from 3.5 to 21.5 percent. This amount of shrinkage in the wool fabrics seemed unduly great in comparison with findings of other workers who have reported shrinkage in hand-laundered wool fabrics after the tenth wash of 7 and 11 percent for the warp direction and 3 and 5 percent for filling (*3, 7*). The same workers reported results as low as 11 and 8 percent, respectively, in warp and filling after 50 launderings. The amount of shrinkage obtained in this study indicates the standard test method (*19*) may be too severe for wool. There is probably enough mechanical agitation to produce excessive shrinkage.

The cotton fabrics ranked next to the wools in dimensional changes, having a range in the warp of 1 percent stretch to 8 percent shrinkage and in filling from zero change to 7 percent shrinkage.

The continuous filament acetate fabrics changed the least. Most of the data for the warp and filling ranged between 0.5 percent stretch and 2.5 percent shrinkage. These results agree with findings Smith (*18*) reported on acetate rayon.

Except for two fabrics (spun acetate-viscose fabric No. 5 and spun viscose fabric No. 1) which shrank 8.0 and 12.5 percent, respectively, in the warp, the groups made up wholly or in part of viscose rayon changed less than the cottons but more than the acetate rayons. At least two fabrics in each of the rayon groups stretched in the filling with laundering whereas only one of the cottons stretched in the warp. None of the rayons stretched in the warp direction and none of the cottons in the filling.

In the main, dimensional changes resulting from laundering the cottons and rayons tended to agree with those found in other researches. Searle and Mack (*17*) reported that in one large study more viscose

rayon than cotton fabrics shrank a negligible amount and that the cottons generally shrank more than the viscose rayons. In the study being reported some of the rayons, especially the spun viscose rayons, were stable like cotton. This agreed with the findings of Clayton (*4*). Workers have found that some rayons shrank with one wash and stretched with another and that other rayons showed progressive shrinkage (*1*). The rayons in the Bureau's study exhibited only slight tendencies toward progressive shrinkage. The excessive shrinkage in a few of the rayons may have been caused by great stretching during their manufacture (*13, 14*).

## Changes Resulting From Dry Cleaning

When dry-cleaned the wools ranged in dimensional change from 4 percent stretch in the filling of one fabric to 9.5 percent shrinkage in the warp of another. The cottons ranked next with a 1 percent warp-wise stretch in one fabric and a 5 percent shrinkage in the filling of another. The four groups of rayon fabrics were about alike in their reaction to dry cleaning. With a few exceptions the data for the four groups ranged between 1.5 percent stretch to 3.0 percent shrinkage.

## Results of Wet Cleaning

In wet cleaning, as in laundering and dry cleaning, the wools exhibited the greatest changes. The cottons ranked next. The continuous filament acetates changed the least, both in length and width. Wet cleaning caused two of the continuous filament viscose and one of the spun viscose fabrics to stretch in the filling throughout the five cleanings. Three continuous filament acetates and one spun viscose fabric stretched slightly fillingwise in the first two cleanings then shrank with subsequent treatments.

## Comparative Effects of Cleaning Procedures

The results of this study showed that the cotton and wool fabrics shrank most in laundering and least in dry cleaning. The dimensional changes of the continuous filament acetate fabrics were about the same by all three cleaning methods. In the continuous filament viscose fabrics the dimensional changes in laundering and wet cleaning were about the same and were greater than those in dry cleaning. Laundering caused the most shrinkage in the spun viscose fabrics; wet cleaning produced the most shrinkage in the mixed acetate and viscose fabrics.

Dry cleaning produced less shrinkage than wet cleaning, which is in accord with findings of other investigators (*8, 15, 17*). On the whole, laundering caused greater shrinkage than wet cleaning. This was contrary to previous findings (*8, 15*) where wet cleaning done in accordance with a widely used test procedure (*19*) produced the greater shrinkage. This difference in results may be attributed to the length of time the fabrics were wet and to the method of drying. In the study being reported the wet-cleaned fabrics were wet only 9 minutes and were extracted after rinsing whereas in the previous study (*8, 15*) fabrics wet-cleaned by the test procedure were wet 20 minutes and were not extracted.

## Effect of Tension During Pressing

Figures 9 and 10 show the effect of pressing under ½, 2, and 4 pounds of tension on the dimensional changes in the six groups of fabrics laundered five times. In general, increased tension produced less shrinkage or greater stretch in both the warp and filling directions. Also, the fabrics were more easily stretched in the filling direction than in the warp. The rayon fabrics were more easily stretched than the cottons and wools. These findings are similar to those previously reported by Gaston and Fletcher (*9*, *10*).

In a few fabrics where increased tension lessened shrinkage in one direction there was increased shrinkage in the other. This was the case with cotton fabric No. 1 with the 4-pound tension and spun viscose fabric No. 2 with the 2-pound tension (figs. 9 and 10). The warp shrank in order to allow the more extensible filling to stretch with the increased tension.

In most fabrics the greater shrinkage was in the warp direction. This was to be expected since warp yarns are under the greater tension during the weaving and finishing of the cloth. Hence upon relaxation they tend to draw up. Where shrinkage was greater in the filling direction, application of higher tensions usually reduced the filling shrinkage.

Dimensional changes in the specimen of each cotton and wool fabric pressed three times under successively increasing tension of ½, 2, and 4 pounds were usually similar to those found in the three specimens of each cotton and wool material pressed under ½, 2, or 4 pounds, respectively. This indicated that the tensions applied successively in pressing the same specimen did not affect the behavior of the specimen in successive cleanings. In other words, the strains set up in the fabrics by pressing under tension disappeared on wetting out.

In the continuous filament acetate and in the spun acetate-viscose materials there was a definite tendency for the specimen pressed under successively increased tensions to be permanently stretched in the filling by the higher tensions. This was noticeable particularly with ½- and 2-pound tension where in the first laundering shrinkage was greater or the stretch considerably less than in any of the subsequent launderings. There was slight evidence of this tendency also in a few fabrics in the spun viscose and continuous filament viscose groups.

## Creep and Restorability of Fabrics

All six groups of fabrics exhibited the flow phenomenon of creep. The deformation resulting from creep under constant load in these fabrics for the comparatively short time interval of 1,000 minutes can be represented by the relation

$$\epsilon = \epsilon_1 + b \log t$$

which is a special case of the law of creep commonly obeyed by many materials expressed by the equation,

$$\epsilon = \epsilon_1 + at + b \log t.$$

$\epsilon$ is the total deformation or strain at time, $t$; $\epsilon_1$ is the initial strain; and $a$ and $b$ are parameters depending on the kind of material and on

the experimental conditions. Since the creep component of the total deformation in these fabrics is represented only by a logarithmetic function of time, the parameter $a$ equals zero.

Parameters of the creep equation for all the fabrics are reported in table 2. The elongation versus time curves for one representative fabric in each of the six groups are shown in figure 11. The straight lines are for the best fitting equations determined by the method of least squares.

The parameters, $b$, the rate of increase of elongation, for both warp and filling for all the fabrics were small, less than 1 percent; but the initial elongations, $\epsilon_1$, were usually considerable, some over 8 percent. Consequently the initial elongation rather than the elongation occurring over a long period of time under tension determines the restorability of these fabrics.

Initial elongations in the warpwise and fillingwise directions of each fabric group were plotted against the corresponding dimensional changes in the specimens laundered five times and pressed under 4 pounds tension (data in table 2). Straight lines which best fitted these data for each group are shown in figure 12.

Even though the initial elongations of the fabrics in each group varied somewhat, the lines reveal that each fiber group followed a definite pattern of performance. The wools and continuous filament acetates deviated most. The elongation of the filling exceeded that in the warp except in three cases. In general the fabrics in each fiber group having the least initial elongation shrank the most.

Since, except for the wools, the initial elongation was usually greater than the shrinkage, the restorability of the shrunken materials to their original size seemed possible.

The various loads used in attempting to restore the specimens laundered five times and pressed under 4-pounds tension and the dimensional changes resulting in these specimens are given in table 2.

The rayons which shrank could easily be restored to their original size by stretching when wet and setting by pressing. All the specimens of the same fabric whether laundered, dry-cleaned, or wet-cleaned required approximately the same tension in stretching. The initial elongations found in the creep measurements usually exceeded the shrinkage in these fabrics.

Some of the cotton and wool fabrics could not be restored even with 12 pounds of tension. After 6 pounds were applied a further increase up to 12 pounds produced little change. Two cotton fabrics—Nos. 1 and 4—had more than one percent shrinkage after pressing under 12 pounds of tension. The initial elongation of fabric No. 1 was negative and that of No. 4 was less than the shrinkage after five launderings. This indicated that in these fabrics increase of crimp was sufficient to cause the shrinkage. The dry-cleaned and wet-cleaned specimens of fabric No. 1 could not be restored but those of No. 4 could be restored.

Even though pressing under 12 pounds of tension greatly reduced the shrinkage of the wool fabrics some of the materials could not be restored to their original dimensions after laundering and cleaning. For example, three of the fabrics could not be restored to their original length and two could not be restored to their original width after laundering. The dry-cleaned and wet-cleaned specimens of two of

the same three fabrics could be restored in length, but the dry- and wet-cleaned specimens of only one of the fabrics could be restored in width.

The initial elongations for the warp of the five wool materials were nearly the same, ranging between 4.8 to 6.3 percent; fillingwise the range was 0.6 to 17.1 percent. The two fabrics which could not be restored in width after laundering had considerably lower initial elongation than the rest. The shrinkage in the wools was due in a large measure to the increase in crimp which in turn was no doubt caused by felting.

TABLE 2.—*Creep of wet fabrics and restorability of specimens pressed under 4 pounds tension and after 5 launderings*

| Group and fabric No. | Parameters of creep equation [1] | | | | Restorability | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Warp | | Filling | | Warp | | | Filling | | |
| | $\epsilon_1$ Initial strain | $b$ Rate of creep | $\epsilon_1$ Initial strain | $b$ Rate of creep | Change after 5 launderings | Load applied | Final change | Change after 5 launderings | Load applied | Final change |
| Cotton: | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Pounds* | *Percent* | *Percent* | *Pounds* | *Percent* |
| 1 | —0.359 | 0.191 | 4.988 | 0.428 | [2]—5.5 | 12 | —3.5 | —2.5 | 12 | —0.5 |
| 2 | 4.673 | .128 | 7.819 | .399 | [3]+ .5 | 1.5 | 0 | 0 | 0 | —1.0 |
| 3 | 2.934 | .104 | 17.181 | .401 | —1.0 | 4 | 0 | +4.0 | 0 | —.5 |
| 4 | 3.539 | .404 | 7.851 | .371 | —4.0 | 12 | —2.5 | —.5 | 5 | —.5 |
| 5 | 5.734 | .234 | 9.288 | .408 | —1.5 | 12 | —1.0 | 0 | 12 | 0 |
| Wool: | | | | | | | | | | |
| 1 | 5.484 | .299 | 17.099 | .099 | —7.5 | 12 | —.5 | +3.5 | 3 | 0 |
| 2 | 6.333 | .233 | .570 | .440 | —19.5 | 12 | —14.5 | —18.5 | 12 | —12.5 |
| 3 | 5.341 | .661 | 18.460 | .555 | —6.5 | 12 | +1.5 | +3.5 | 3 | +1.0 |
| 4 | 5.360 | .160 | 12.484 | .249 | —7.5 | 12 | —4.5 | —3.5 | 12 | 0 |
| 5 | 4.795 | .160 | 7.878 | .348 | —10.5 | 12 | —6.0 | —10.5 | 12 | —4.0 |
| Acetate (continuous filament): | | | | | | | | | | |
| 1 | 2.545 | .260 | 4.732 | .517 | —.5 | 2 | 0 | +2.0 | 0 | +1.5 |
| 2 | 2.257 | .207 | 5.169 | .649 | 0 | 0 | —.5 | +3.0 | 0 | +2.5 |
| 3 | .988 | .303 | 4.309 | .739 | —2.0 | 5 | —.5 | +3.5 | 0 | +2.0 |
| 4 | 1.480 | .280 | 5.872 | .752 | 0 | 0 | 0 | +2.0 | 0 | +2.0 |
| 5 | 1.090 | .140 | 5.880 | .530 | —1.0 | 3 | —1.0 | +1.5 | 0 | +1.5 |
| Viscose (continuous filament): | | | | | | | | | | |
| 1 | 6.351 | .171 | 6.167 | .312 | +1.0 | 1 | 0 | +1.5 | 0 | —.5 |
| 2 | 8.466 | .596 | 7.841 | .306 | +1.5 | 3 | 0 | +2.0 | 0 | +.5 |
| 3 | 7.454 | .304 | 8.840 | .395 | 0 | 3 | +.5 | +.5 | 0 | —1.5 |
| 4 | 8.551 | .366 | 11.973 | .223 | —.5 | 3 | —.5 | +6.0 | 0 | +4.5 |
| 5 | 4.815 | .350 | 9.112 | .342 | —1.0 | 4 | 0 | +1.5 | 0 | —.5 |
| Spun viscose: | | | | | | | | | | |
| 1 | 5.982 | .267 | 11.944 | .339 | —4.5 | 8 | —1.0 | +3.0 | 2 | +1.0 |
| 2 | 6.346 | .426 | 10.792 | .527 | —.5 | 5 | +.5 | +.5 | 2 | 0 |
| 3 | 1.109 | .409 | 8.750 | .450 | —1.5 | 7 | +.5 | +2.5 | 1 | —.5 |
| 4 | 2.417 | .317 | 11.137 | .942 | +1.0 | 6 | +1.5 | +2.5 | 3 | 0 |
| 5 | 4.321 | .336 | 9.020 | .420 | —2.0 | 2 | +.5 | +4.0 | 0 | +1.0 |
| Spun acetate and viscose: | | | | | | | | | | |
| 1 | 6.009 | .489 | 16.618 | .733 | —1.0 | 4 | +.5 | +6.5 | 0 | +1.5 |
| 2 | 5.927 | .542 | 10.620 | .570 | —.5 | 3 | 0 | +3.0 | 1 | —.5 |
| 3 | 5.215 | .545 | 13.463 | .518 | 0 | 5 | +1.0 | +3.0 | 1 | 0 |
| 4 | 3.637 | .387 | 10.034 | .799 | —1.0 | 5 | +.5 | +4.0 | 0 | 0 |
| 5 | 2.939 | .519 | 8.732 | .697 | —3.0 | 12 | +.5 | +1.5 | 5 | +.5 |

[1] $\epsilon = \epsilon_1 + b \log t$. [2] — designates shrinkage. [3] + designates stretch.

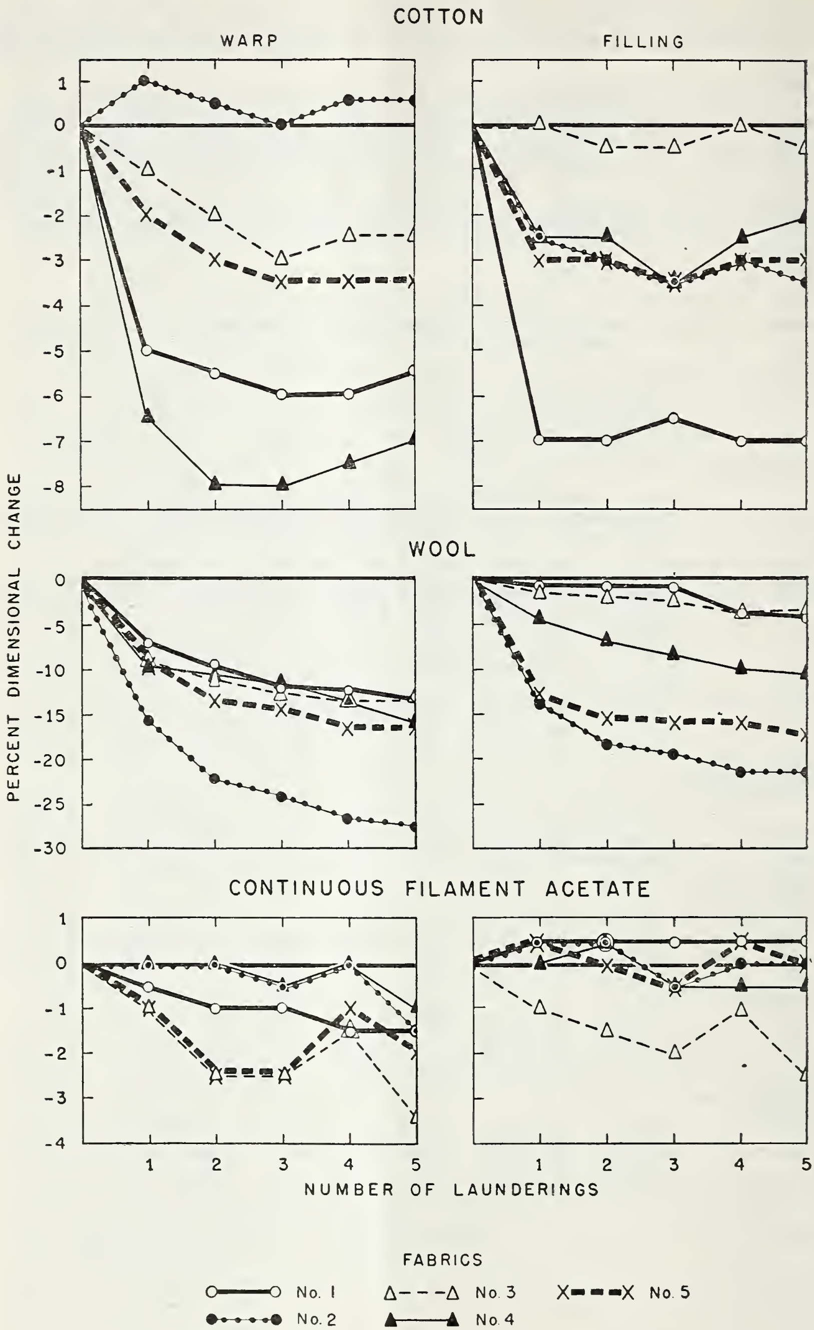


FIGURE 1.—Dimensional changes of cotton, wool, and continuous filament acetate fabrics in laundering by standard test method and pressing under tension of ½ pound.

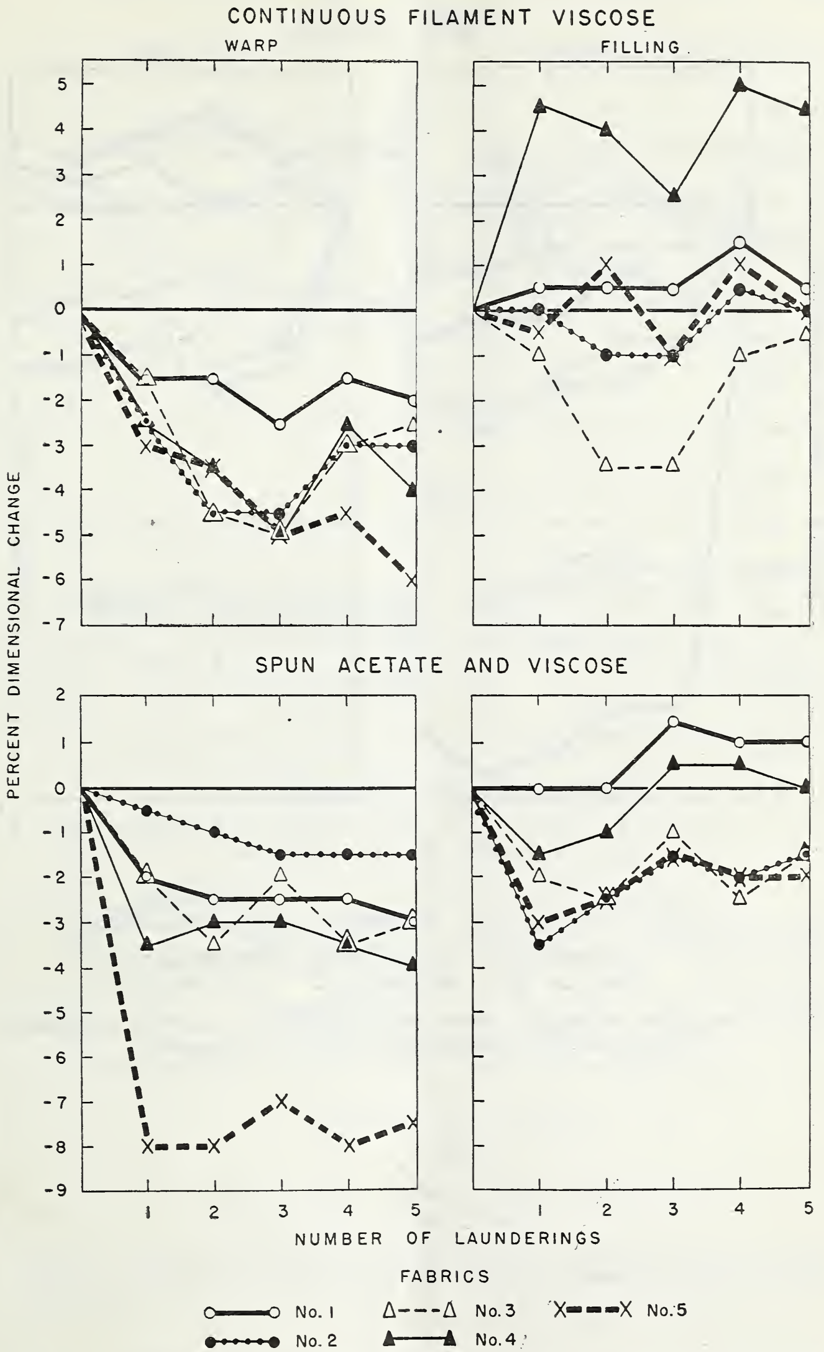


FIGURE 2.—Dimensional changes of continuous filament viscose and of spun acetate and viscose fabrics in laundering by standard test method and pressing under tension of ½ pound.

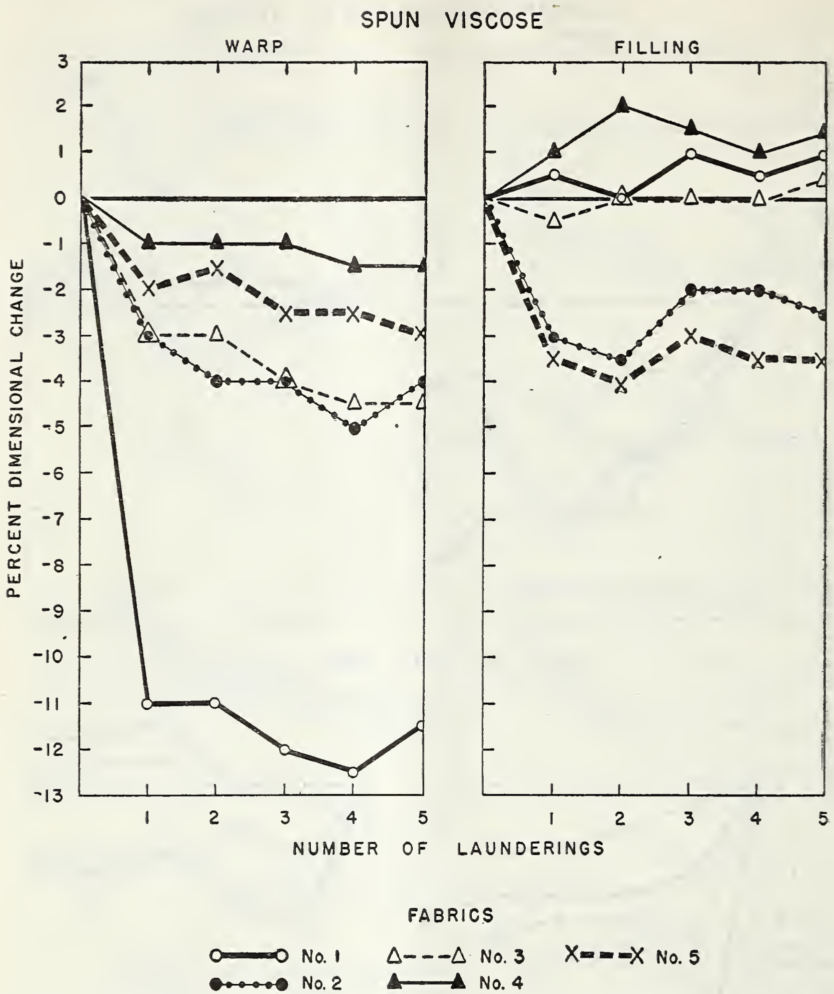


Figure 3.—Dimensional changes of spun viscose fabrics in laundering by standard test method and pressing under tension of ½ pound.

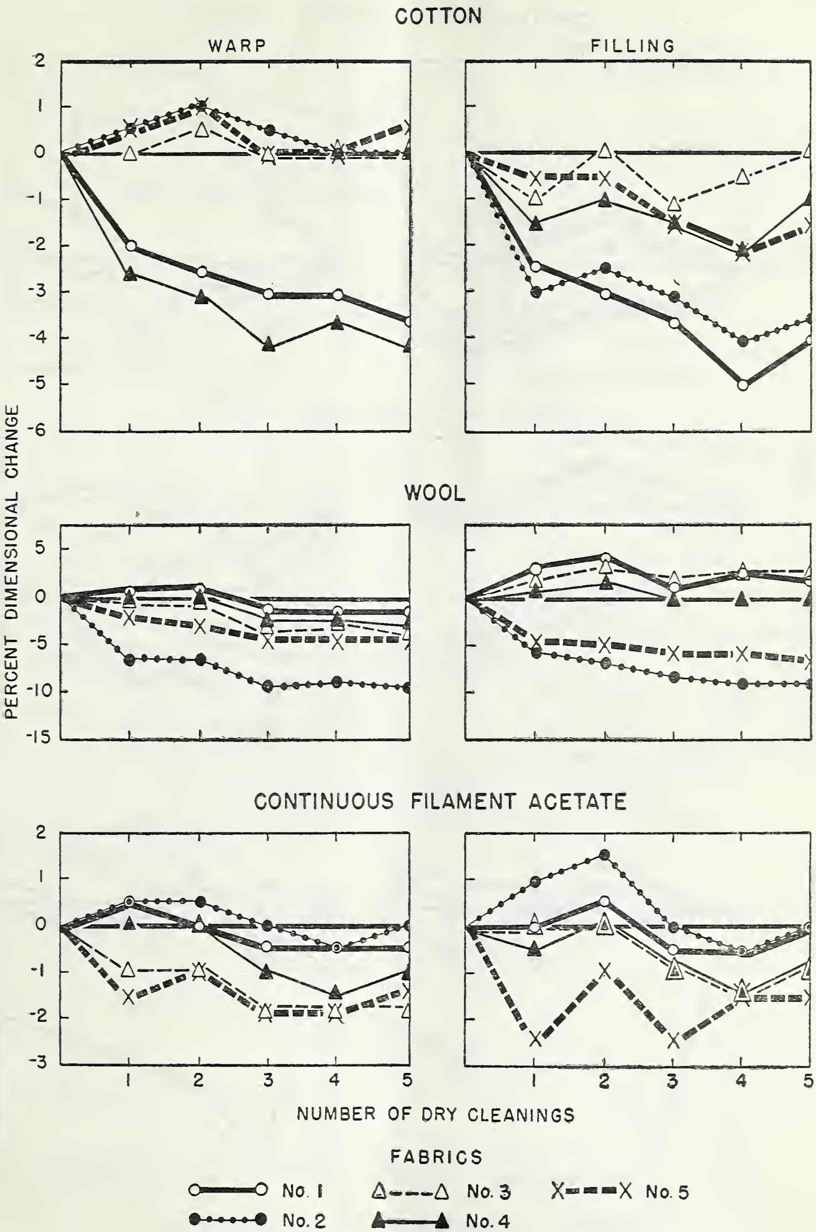


FIGURE 4.—Dimensional changes of cotton, wool, and continuous filament acetate fabrics in dry cleaning by the dry procedure and pressing under tension of ½ pound.

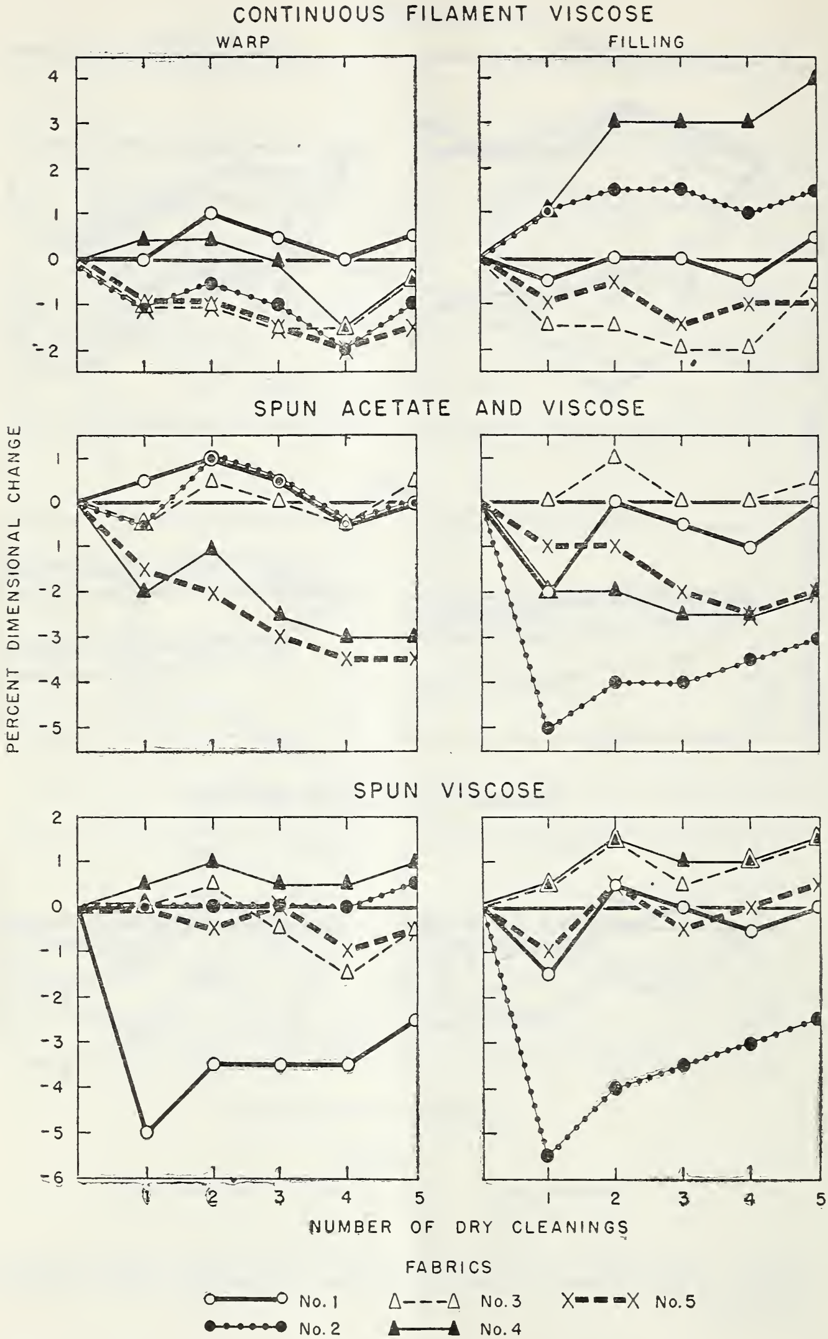


FIGURE 5.—Dimensional changes of continuous filament viscose, spun acetate and viscose, and spun viscose fabrics in dry cleaning by the dry procedure and pressing under tension of ½ pound.

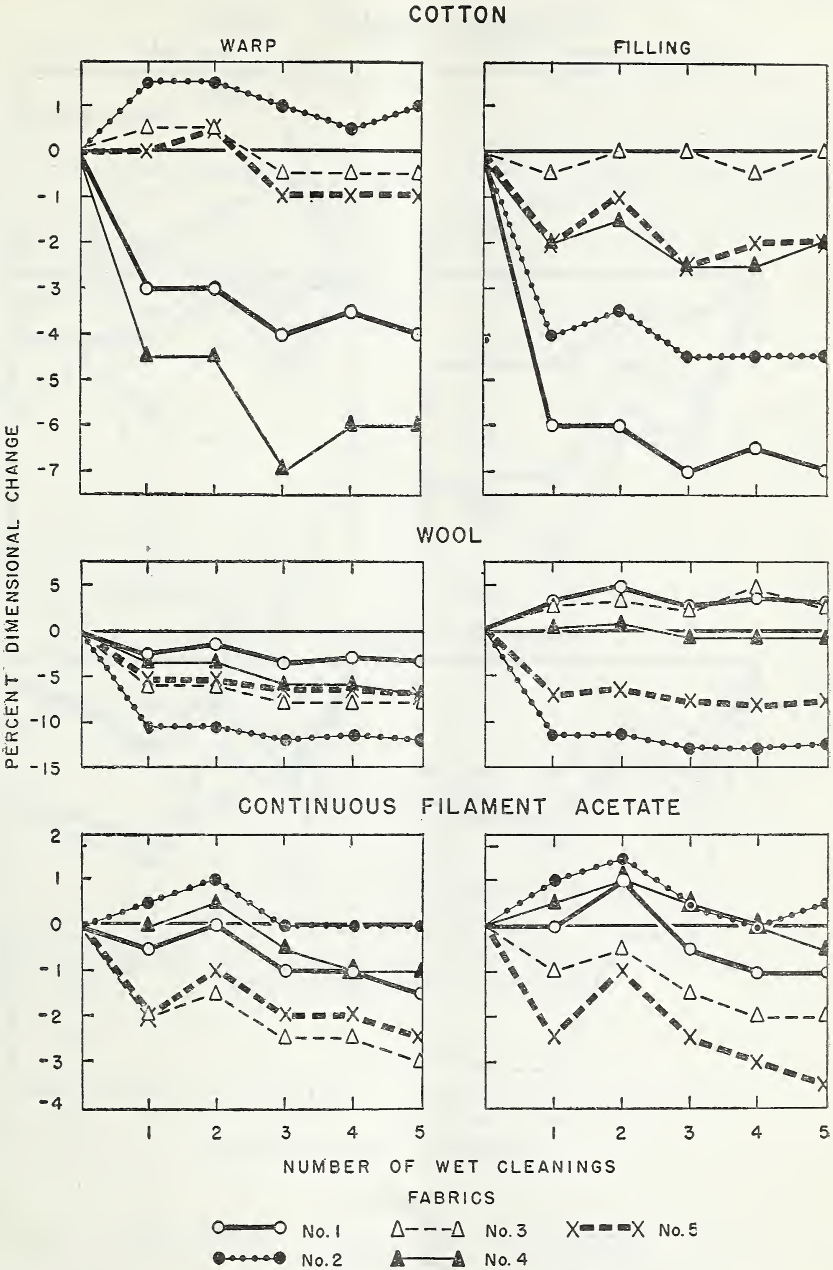


FIGURE 6.—Dimensional changes of cotton, wool, and continuous filament acetate fabrics in wet cleaning and pressing under tension of ½ pound.

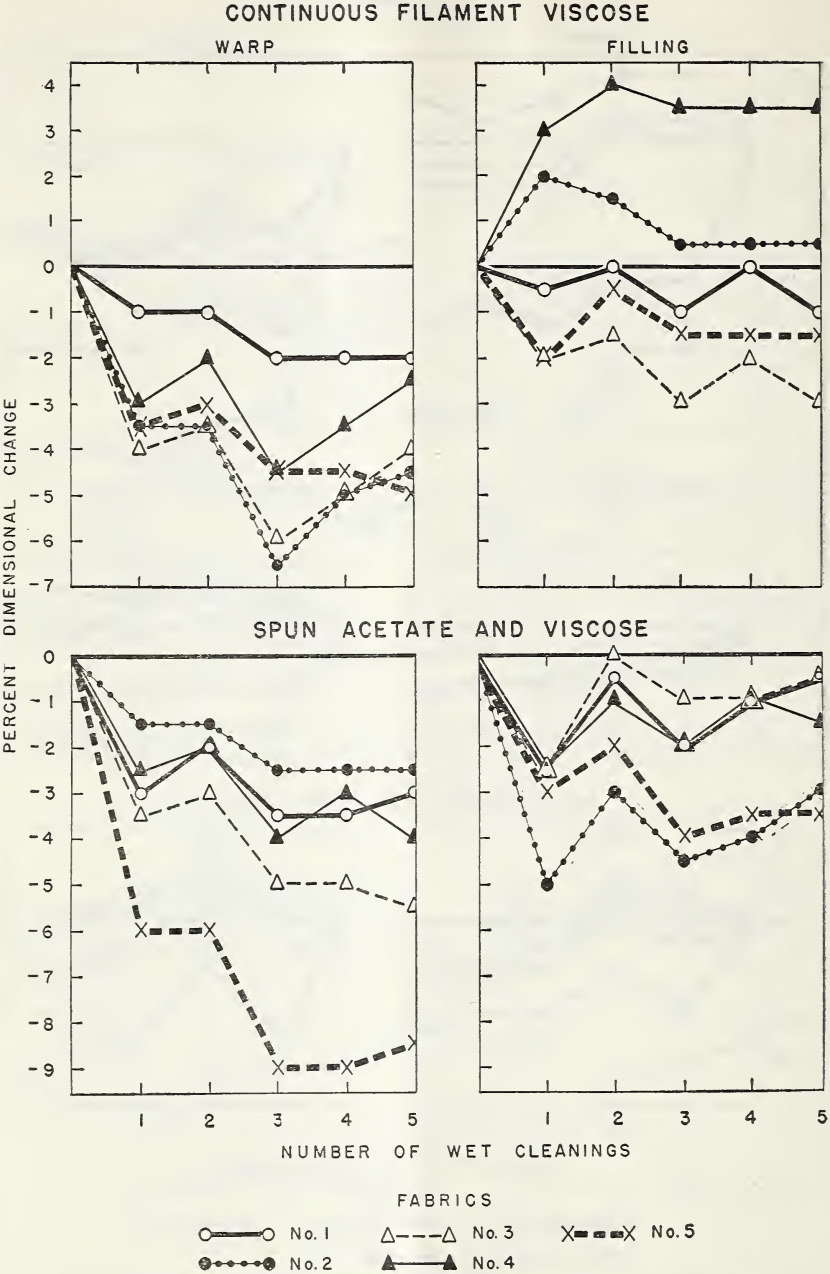


FIGURE 7.—Dimensional changes of continuous filament viscose, and of spun acetate and viscose fabrics in wet cleaning and pressing under tension of ½ pound.

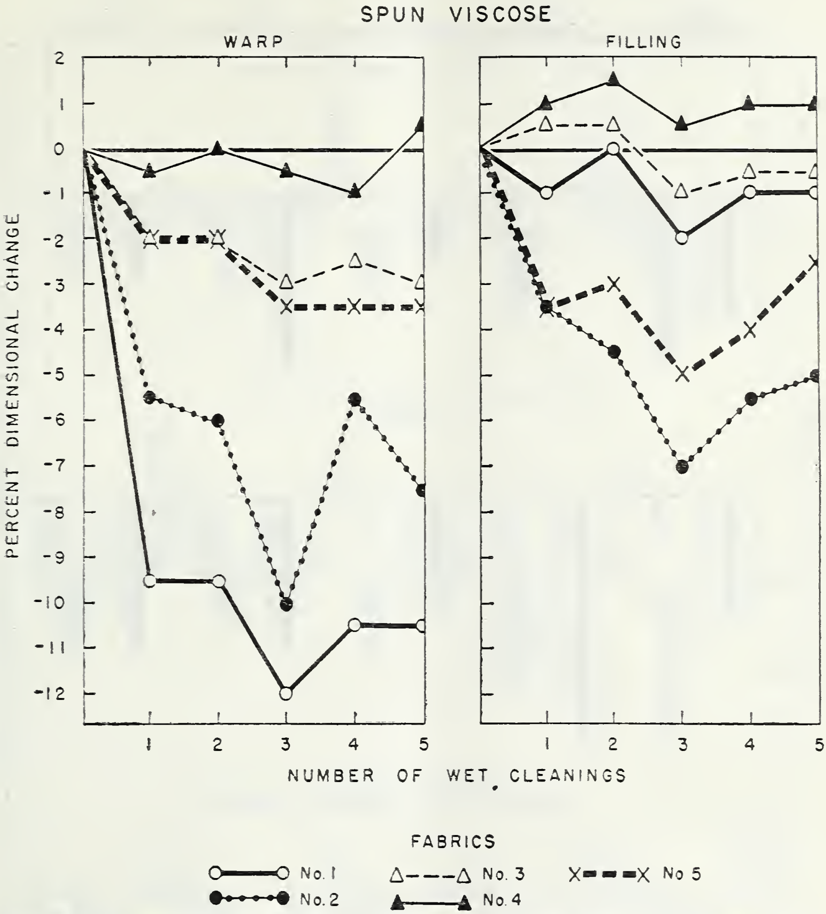


FIGURE 8.—Dimensional changes of spun viscose fabrics in wet cleaning and pressing under tension of ½ pound.

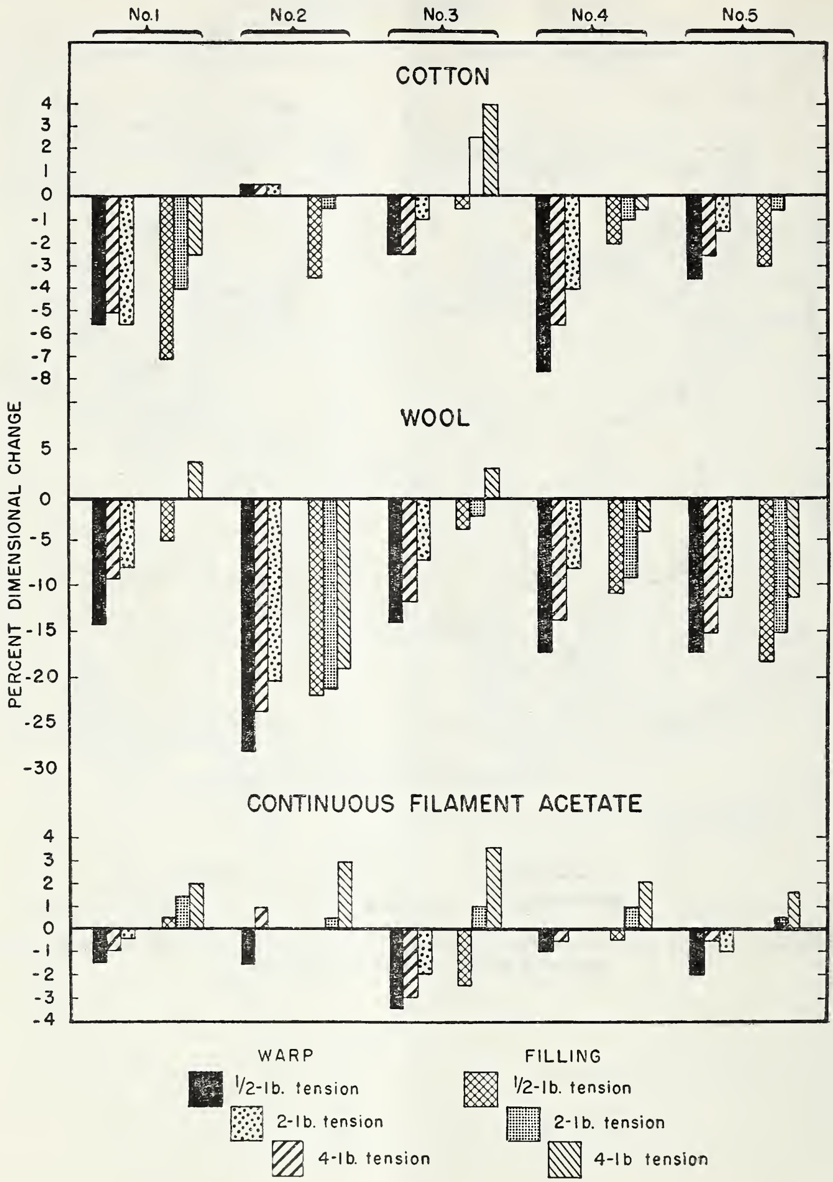


FIGURE 9.—Effect of pressing under various tensions on the dimensional changes of cotton, wool, and continuous filament acetate fabrics in five launderings.

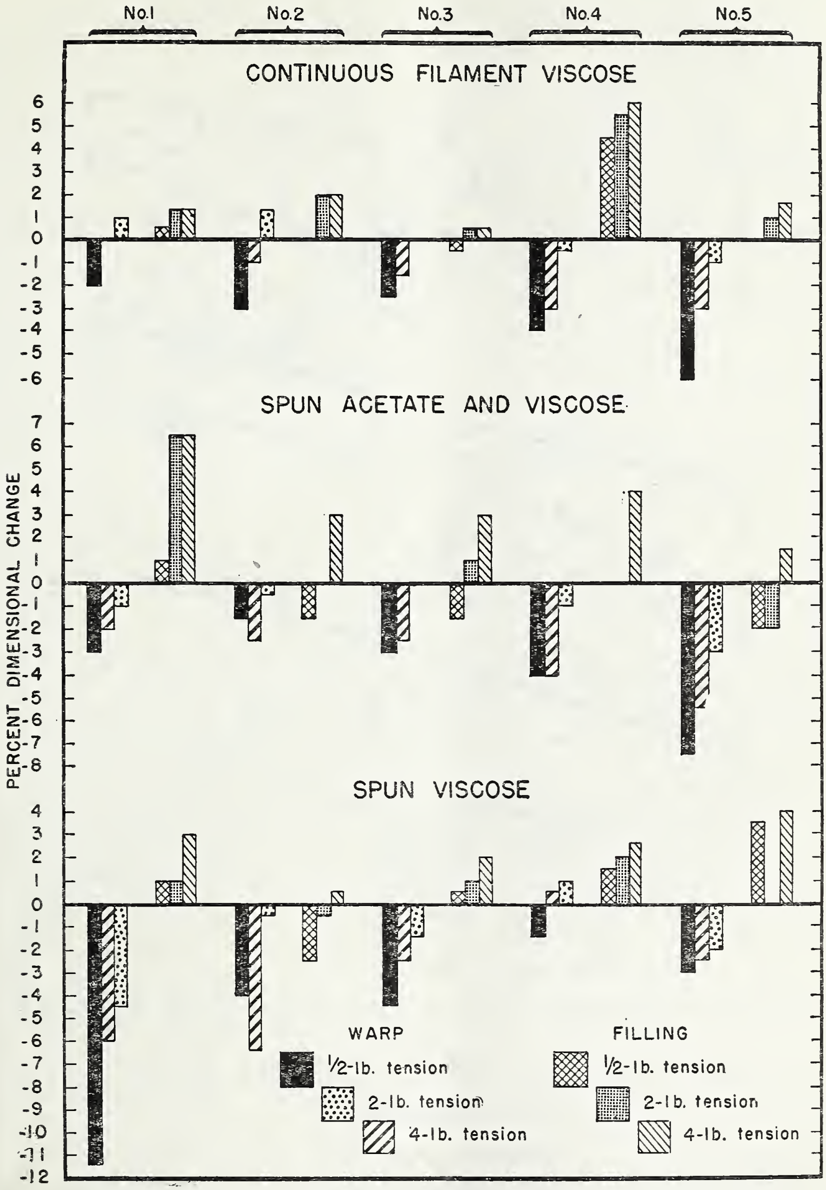


FIGURE 10.—Effect of pressing under various tensions on the dimensional changes of continuous filament viscose, spun acetate and viscose, and spun viscose fabrics in five launderings.

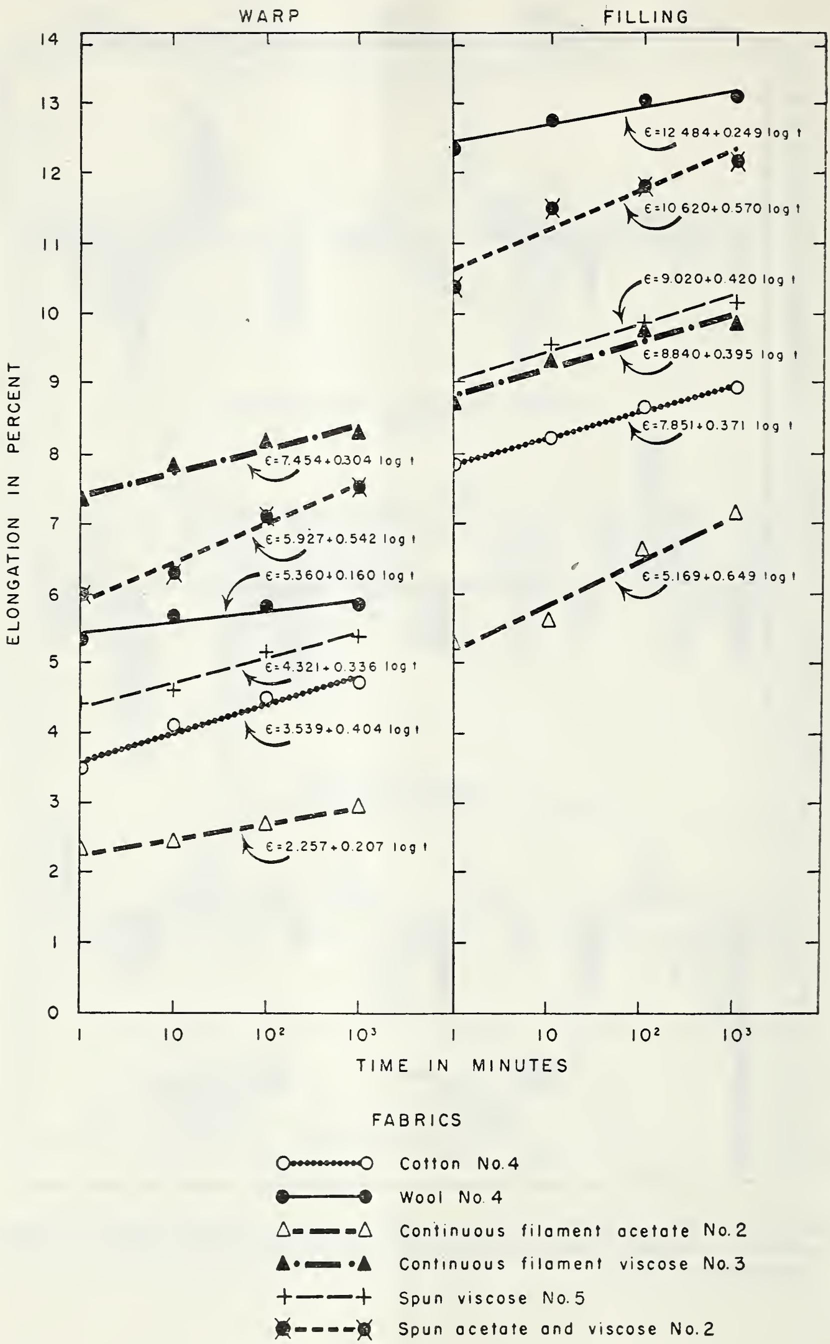


FIGURE 11.—Creep in wet fabrics under constant load.

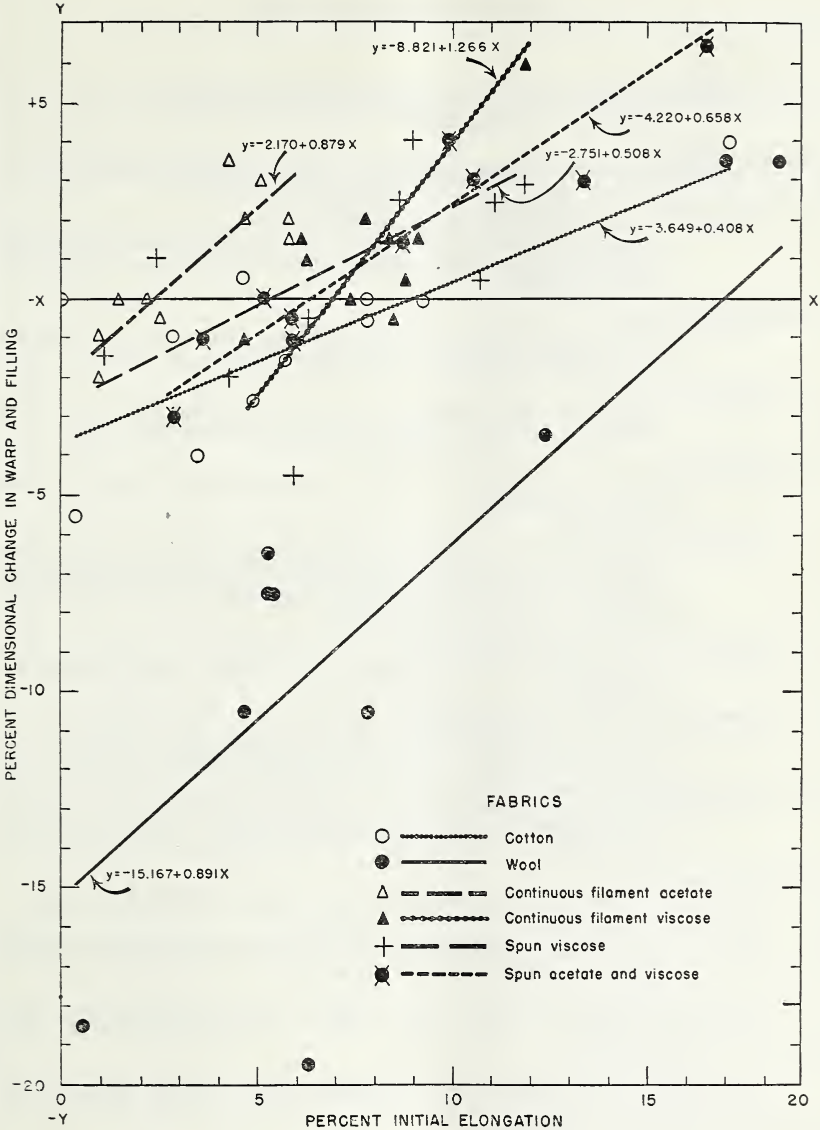


FIGURE 12.—Initial elongation in creep of wet fabrics vs. dimensional change of specimens after five launderings and pressings under 4 pounds tension.

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